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A FACILITATED DISCRETE EVENT SIMULATION FRAMEWORK TO SUPPORT ONLINE STUDIES: AN INTERVENTION IN A SMALL ENTERPRISE

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ABSTRACT

Considering some challenges that prevent the expansion of discrete event simulation studies, such as financial constraints to invest in the data collection of large samples and to hire qualified people for data analysis and for developing complex models, this paper aims to propose a framework to support simulation studies where it is not widely used, adopting facilitated modeling. Since the facilitated DES frameworks in the literature focus on healthcare and face-to-face meetings, the present work offers a framework for simulation projects in production systems, which also supports online interventions. After its development, the FaMoSim (Facilitated Modeling Simulation) framework was applied in a real case to evaluate its applicability. In the application, it was possible to carry out a faster and more flexible online modeling process, create a simple computer model that does not require a complex data collection structure nor a specialist team, and assist the stakeholders in identifying improvements.

1 INTRODUCTION

The use of computer simulation has been emphasized as a crucial instrument for decision-making, as pointed out by Mourtzis (2020). Its usefulness has been highlighted in various domains such as military operations, logistics, hospitals, and particularly manufacturing processes (Gabriel et al. 2022). Although researchers and practitioners widely spread the use of simulation, it still presents an ample scope for investigation, as noted by Mourtzis (2020). Furthermore, a new era of decision-making, characterized by increasingly efficient processes and decisions based on emerging technologies has emerged. This has led to the development of more agile and flexible simulation models, as highlighted by Rodic (2017) and Santos et al. (2020). Nevertheless, it is worth noting that several businesses and managers are still unable to reap the benefits of simulation (Skoogh et al. 2012; Teerasoponpong and Sopadang 2021; Oliveira et al. 2022). Particularly in industrial environments with a low or medium degree of development, several challenges are encountered, such as significant investments and process structure changes, as highlighted by Moeuf et al. (2018), Santos et al. (2020), Choi and Kang (2018), and Goodall et al. (2019).

The use of Discrete Event Simulation (DES) might be limited in certain contexts, including situations where (i) there are financial limitations for gathering large sample data and hiring qualified data analysts (Teerasoponpong and Sopadang 2021; Saez et al. 2018); (ii) there is insufficient data or operational data is unavailable (Omri et al. 2020; Ivers et al. 2016; Byrne et al. 2013); (iii) there is a shortage of experts with the necessary skills and knowledge to utilize DES and create intricate models that represent the characteristics and behaviors of physical systems (Teerasoponpong and Sopadang 2021; Mittal et al. 2018); and (iv) when there is a restricted simulation time and a need for an agile process (Barlas and Heavey 2016).These characteristics above are found mainly in small and medium-sized companies (Oliveira et al. 2022).

Regardless of the level of development and investment in production systems, a crucial feature of simulation projects is the use of adaptable models, as observed in research by Rodic (2017), Vieira et al. (2018), and Santos et al. (2021). To simplify the various steps involved in simulation projects, Facilitated Modeling has been highlighted as a good alternative, according to Robinson et al. (2014).

In exploratory research of the literature in recent years, Oliveira et al. (2022) conducted a study comparing the challenges of implementing DES in industrial settings with facilitated DES frameworks available in literature. The authors identified an opportunity to create a facilitated DES framework for use in productive processes since all evaluated works focused in healthcare environments and none of them addressed all the challenges associated with simulation. Furthermore, the authors noted that online communication resources have not been considered in the frameworks, despite the fact that virtual meetings are becoming increasingly prevalent. Standaert et al. (2021) have predicted an upsurge in virtual meetings in the upcoming years, and Oliveira et al. (2022) believe that developing new methods for conducting facilitated DES online would revolutionize DES applications. Consequently, more applications are required to expand the technique to other fields (Kotiadis and Tako 2021; Tako et al. 2019; Kotiadis and Tako 2018; Robinson et al. 2014).

Consequently, there are opportunities for research involving the development of methods and steps focused on facilitated modeling and simulation in production systems. This study aims to propose a framework that outlines the key steps to be followed in an online facilitated DES study. Additionally, the framework's applicability was tested by applying it to a real object of study.

Even though the proposed framework can be applied in any production system, regardless of size and complexity (Oliveira et al. 2023), this article presents an application in a small company, which is a context where DES is not widely applied due to the characteristics and limitations of Small and Medium-Sized Enterprises (SME) (Oliveira et al. 2022; Byrne et al. 2021; Ivers et al. 2016).

The present article contributes to the existing literature by presenting an online facilitated DES framework that considers the challenges associated with use of simulation, particularly in SMEs, and guides an online facilitated DES without requiring visits to the study site. The framework was tested in an industrial context, involving a small company, providing both theoretical and practical contributions. From a theoretical point of view, this study discusses an online application of facilitated DES in small companies, whereas from a practical perspective, it assists managers in the decision-making. In the current era of decision-making based on emerging technologies (Rodic 2017; Santos et al. 2020), offering an online application of facilitated DES contributes to the literature that aims to incorporate emerging technologies into simulation.

The rest of the paper is as follows: section 2 presents a theoretical background, while the proposed approach is described in Section 3. Section 4 is dedicated to applying the proposed framework to real object of study. Finally, Section 5 focuses on the conclusions and future directions.

2 THEORETICAL BACKGROUND

2.1 Challenges in Applying DES

Simulation models are widely adopted to facilitate decision-making due to their flexible nature and financial advantages (Pereira et al. 2015). In this case, manufacturing systems is a prominent area of application for simulation projects, and Discrete Event Simulation (DES) is the primary type of simulation employed in this context (Scheidegger et al. 2018).

The integration of simulation models with various decision support techniques has become widespread, particularly in the combination of simulation with forecasting techniques, optimization algorithms, Artificial Intelligence (AI) models, Virtual Reality, and Augmented Reality interfaces, among others (Amaral et al. 2022; Mourtzis et al. 2020; Santos et al. 2020). Moreover, the Industry 4.0, the fourth industrial revolution, has had a significant impact on simulation-based decision-making (Santos et al. 2020), since new communication and connection technologies and process automation have enabled greater integration between physical and virtual environments. However, these approaches may not be available to all companies, particularly those in low-to-medium development industrial environments, where significant investments and changes in process structure might be not feasible (Moeuf et al. 2018; Santos et al. 2020; Goodall et al. 2019; Choi and Kang 2018).

Studies suggest that the utilization of DES in SMEs is limited due to their unique characteristics and constraints (Oliveira et al. 2022; Byrne et al. 2021; Ivers et al. 2016). These limitations include financial constraints that hinder investment in data collection and hiring of qualified personnel for data analysis (Teerasoponpong and Sopadang 2021; Saez et al. 2018); insufficient data or unavailability of operational data (Omri et al. 2020; Ivers et al. 2016; Byrne et al. 2013); a shortage of experts with the necessary skills and knowledge to utilize DES and develop complex models that accurately represent the characteristics and behaviors of physical systems (Teerasoponpong and Sopadang 2021; Mittal et al. 2018); and limited simulation time that requires efficient and agile processes (Barlas and Heavey 2016). These characteristics mentioned above are present in SMEs, but are not restricted to these companies. It means that in contexts where they are present, DES studies are scarcer (Oliveira et al. 2022).

To address the challenges mentioned earlier, several authors have suggested the use of facilitated modeling in conjunction with DES. Despite limitations regarding the availability and collection of data for the model building phase, Robinson (2001) and Robinson et al. (2014) argue that the absence of precise data do not limit the utilization of DES models. Accordingly, DES was employed in a facilitated mode.

2.2 Facilitated DES

Facilitated DES intend to foster comprehension and learning of the real system by initiating discussions about the problem with the aid of a simple and quicker model that can be discarded after the intervention (Robinson et al. 2014). This offers flexibility and swiftness to simulation projects. As Robinson et al. (2014) suggest, the model's accuracy is not evaluated; rather, it facilitates discussions and comprehension of the issue. The authors also noted that facilitated simulation has emerged as an alternative to conventional approaches due to the complexity and extended development time of models. Tako et al. (2019) further highlight the growing popularity of facilitated simulation in recent years, with several works in the literature featuring this approach.

In addition, the main characteristics of facilitated DES are: (i) a participatory approach between modelers and stakeholders; (ii) simplified data collection; (iii) agile modeling; and (iv) focus on satisfactory solutions over optimal ones. This has been acknowledged by several authors who recognize the potential of DES in the facilitated mode and emphasize the need for further research (Robinson et al. 2012; Robinson et al. 2014; Tako and Kotiadis 2015; Proudlove et al. 2017; Kotiadis and Tako 2018; Tako et al. 2020; Harper et al. 2021).

Upon exploring recent literature, several studies have implemented facilitated DES in the healthcare field to aid in decision-making, as observed in works by Robinson et al. (2014), Tako and Kotiadis (2015, 2018), Proudlove et al. (2017), and Tako et al. (2019, 2021). Oliveira et al. (2022) have presented facilitated DES frameworks from the literature and concluded that developing a framework for diverse contexts beyond hospitals is crucial. However, the existing frameworks are not applicable without customization, since they were designed specifically for healthcare. Furthermore, the authors noted that online communication resources have not been considered in the frameworks. With virtual meetings anticipated to become more common in the future (Standaert et al. 2021), Oliveira et al. (2022) suggested that innovating the application of facilitated DES online would advance DES techniques.

3 PROPOSED APPROACH

The FaMoSim (Facilitated Modeling Simulation) framework was designed following the Action Research (AR) cycle proposed by Coughlan and Coughlan (2002), which is divided into three phases: The first one aims to understand the purpose of the situation. The second phase comprises six steps: data collection, data feedback, data analysis, action planning, implementation, and evaluation. And the last phase is a monitoring meta-step. The objective of this paper is to address the existing gaps in the literature by presenting a facilitated DES framework that can be used online, even in situations that present challenges for DES applications, such as industrial processes. Figure 1 illustrates the FaMoSim framework.

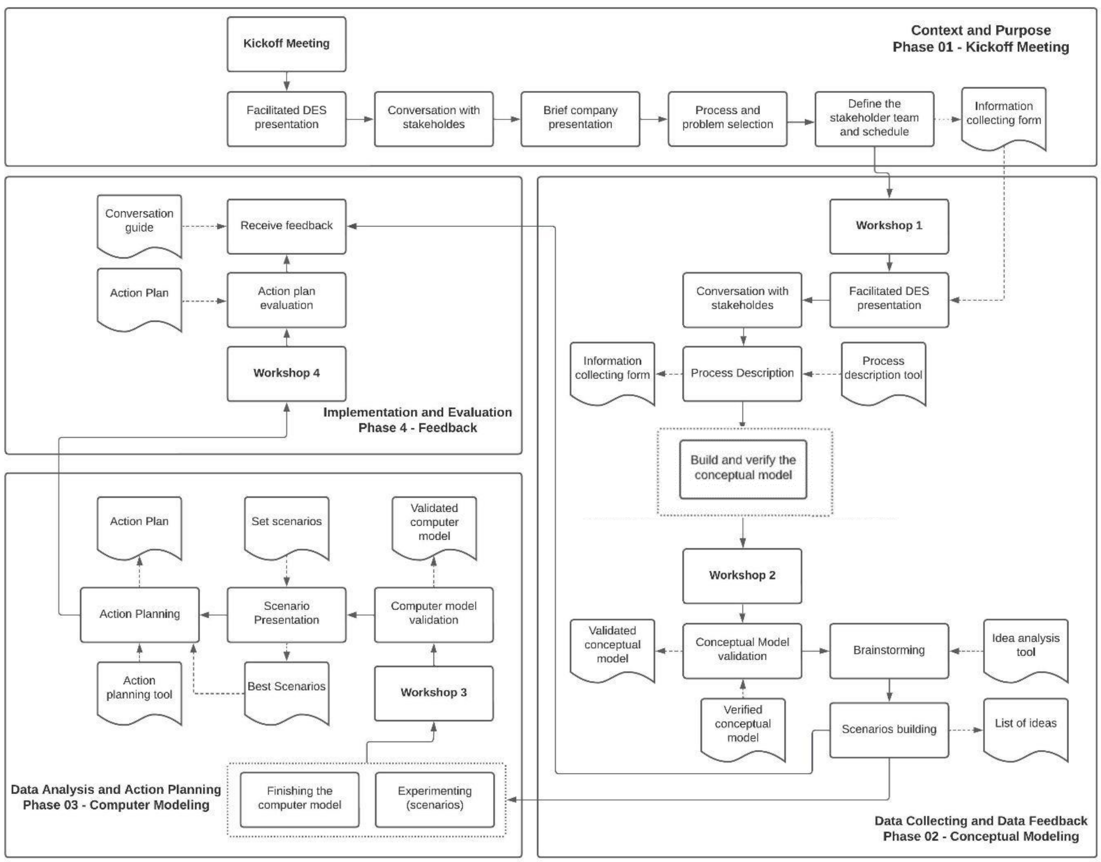

Figure 1: The FaMoSim framework.

We used the AR method to develop the framework. The method was utilized in the development and application of the SimLean Facilitate (Robinson et al. 2014) and PartiSim (Tako and Kotiadis 2015) facilitated DES frameworks. The AR is a suitable method to develop the framework since it provides several benefits, including: (i) facilitating researcher and client (company) interaction, which is crucial for result analysis and framework improvement through client feedback; (ii) generating new knowledge for the literature, as the proposed framework can serve as a structure for future DES studies and projects; (iii) aiding in problem-solving.

The framework proposed in this paper introduces an innovative approach for facilitated DES by conducting online interventions, enabling virtual participation for some members while others attend in-person. As some researchers suggest, hybrid meeting formats are expected to become more prevalent in the post-COVID-19 era (Hameed et al. 2021; Richter 2020). Thus, the possibility of virtual participation allows DES projects to expand their geographic reach and application in different locations. While stakeholders attend in-person, researchers participate remotely. The company is required to permit recording of the meeting to facilitate information gathering about the process under study.

The FaMoSim framework is composed of four stages: Kickoff Meeting, Conceptual Modeling (divided into workshops 1 and 2), Computer Modeling (workshop 3), and Feedback (workshop 4). Each phase has a specific objective, a set of activities to be executed, expected results, and tools to support the process, with verification and validation being performed throughout. It is important to note that stakeholder availability may impact the lead time, but it is recommended that the process does not exceed three months, with each meeting lasting approximately 60 minutes. The main difference between traditional DES and this approach is that simulation occurs within a facilitated environment, allowing stakeholders to share their preferences, explore alternatives, and actively participate in the process.

The project team is composed of two teams: the modeling team and the stakeholder team. The modeling team comprises a facilitator and a modeler, who can be the same person. Meanwhile, the stakeholder team consists of two to four members from the company. The main goal of the models developed through the FaMoSim framework is to provide a better understanding of the problem and assist the stakeholders in identifying potential process improvements. Therefore, the DES model must focus on the key elements of the system and have low complexity. The required data for the model can be estimated by process experts (Robinson et al. 2014) or obtained from data already collected by the company. Table 1 shows the steps of FaMoSim framework and more details can be found in Oliveira et al. (2023).

Table 1: Phases, activities and tools of FaMoSim framework.

Phases and purpose	Activities	Tools
Context and Purpose - Phase 01 Kickoff Meeting Purpose: Motivate teamwork on a project; Make a decision.	Clarify to stakeholders what the facilitated DES is, its benefits for the company and how the project will be carried out (framework explanation); The stakeholders share with the modeling team the possible process to study and define which people can make up the stakeholder team.	Information collecting form.
Data collecting and Data Feedback - Phase 02 Conceptual Modeling Workshop 1 Purpose: Clarify a concept; Share information. Workshop 2 Purpose: Generate consensus on the process (validation);	Workshop 1: Clarify to the other stakeholders what facilitated DES is; Describe the proposed process by the stakeholder team. Workshop 2: Validate the conceptual model using the face-to-face technique with all teams; Set up a virtual brainstorming session with the stakeholders to develop ideas to improve the system and test them in the simulation model; Build scenarios, where the stakeholders	Workshop 1: Process description tool; Information collecting form. Workshop 2: Idea analysis tool

Brainstorm ideas for process improvement.	should suggest scenarios that do not require complex adaptations in the computer model. A list of ideas is built containing the scenarios that will be tested in the computer model.	
Data Analysis and Action Planning - Phase 03 Computer modeling Workshop 3 Purpose: Generate consensus on the process (validation); Find a solution to a problem that has arisen.	Conduct face-to-face computer model validation; Present the scenarios and analyses for discussion. The team chooses the best indicative results; Establish an action plan.	Action planning tool
Implementation and Evaluation - Phase 04 Feedback Workshop 4 Purpose: Exchange of information; Receive feedback	Follow up on the action plan, gathering information about what changes were made and the results obtained; Receiving feedback from the stakeholders about how this experience was for them.	Conversation guide

Following workshop 1, the modeling team is responsible for constructing and validating the conceptual model. Additionally, they should initiate the computer model simultaneously and complete it only after validating the conceptual model. Kotiadis et al. (2014) suggest that creating preliminary materials for the workshops can prevent wastage of unproductive time during the meeting.

During workshop 2, the stakeholders might choose between proceeding with computer modeling or implementing the new ideas solely based on the conceptual modeling analysis in the real system. Robinson (2008) asserts that if the findings of the conceptual model meet the stakeholders' requirements, the project can be concluded at this stage.

The computer modeling phase consists of finishing the computer model, experimenting and elaborating an action plan for possible improvements according to the scenarios. In this way, the modeling team should finish the computer model and set up the scenarios as activities carried out before the workshop 3.

In workshop 3 of the study, the company has the option to not collaborate with the modeling team to develop the action plan. In such cases, if there are any unexpected delays in implementing changes in the real system, the stakeholders may choose to discontinue the study at this stage. In the event that stakeholders decide to halt the study at either the conceptual modeling stage (workshop 2) or computer modeling stage (workshop 3), we recommend completing the second objective of the feedback phase in workshop 4.

The meta-step of AR monitoring is an ongoing process in the DES project, which is facilitated at various stages of the AR methodology. Researchers monitor each stage of the project and keep track of stakeholder feedback through emails that are sent after each workshop. These emails contain the workshop results and seek the stakeholders' perception of the process by asking them questions. Moreover, the stakeholders' comprehension of the project is continuously monitored by the researchers during the project execution.

They ask the stakeholders if they have understood the process, if they have any questions, and if they agree with the ongoing actions.

The proposed framework provides support for researchers who intend to conduct online facilitated DES by providing recommendations for successful hybrid meetings. These recommendations mainly pertain to the number of team members and meeting durations. Face-to-face meetings can be extended up to 3 hours (Robinson et al. 2014). However, this duration is difficult to achieve in online meetings as members are more prone to distractions (Oeppen et al. 2020). To address this issue, the framework divides the activities in each workshop to ensure meetings do not exceed the stipulated time and compromise results. Another important consideration in online meetings is the number of project team members. The literature suggests that too many participants (more than five) can negatively impact the effectiveness of the meeting (Standaert et al. 2021; Itzchakov and Grau 2020). However, the literature reports that the duration time and number of participants are concerns that the frameworks fail to address (Oliveira et al. 2022). This problem is addressed in FaMoSim as the workshop activities were organized to allow meetings of up to 60 minutes. At the beginning of each study, it was clarified to the key stakeholder that only four stakeholders could participate in the study, following the literature recommendation.

4 RESULTS AND DISCUSSIONS

This section provides our observations of using the FaMoSim framework in a small company. It is a clothing manufacturing company and the processes under observation is the sublimation of clothing. This is a process of low complexity, comprising of two primary activities, which are: arranging the fabric in the machine and waiting for the clothes to be pressed (machine time). This cycle is repeated four times, and then the clothing is ready for the next stage.

The objective of the study is to enhance the productivity of the process by creating several scenarios to aid in the decision-making process regarding the purchase of a new machine. The main question being considered is "what type of machine would be best to purchase to increase productivity?" The data used in the model were estimated by the owner of the company, who was the sole stakeholder involved in the entire project. The owner of the company is responsible for overseeing the processes and resolving all issues related to the production lines.

4.1 FaMoSim in A Real Case

Throughout the study, all communication with the stakeholder was conducted virtually, either via email or cell phone. Prior to each meeting, an email was sent to the stakeholder outlining the agenda and providing a brief explanation of the topics to be discussed. The study consisted of four 60-minute meetings, which were recorded for reference.

The kickoff meeting took place between the facilitator and the key stakeholder, the company owner. The activities of this first meeting were carried out, with a facilitated DES explanation followed by a company presentation. The stakeholder gave some background information about the company and its processes. As a clothing factory, there are seasonal demands, and the most stable process in the factory was the sublimation process. In other words, the demand was constant throughout the year. This sublimation process was new to the company, and the key stakeholder wanted to increase its productivity. Thus, the process was chosen for the study.

The first meeting lasted for 50 minutes, but there was a connection problem that required 10 minutes to return to the meeting. In the stage of defining the stakeholder team, the company owner did not see the need to add more members since he is the responsible for the process, having almost all the knowledge of the process. Therefore, the remaining meetings were held with the presence of the key stakeholder and the facilitator only. Workshop 1 was scheduled for the following week, and thus, the kickoff meeting was concluded.

In workshop 1, it was not necessary to clarify to the other stakeholders what facilitated DES is, since only the company owner was participating in the study. Therefore, we proceeded to the process description activity. The key stakeholder described the process by itself without the facilitator first asking questions, using the process description tool. The facilitator allowed this behavior from the key stakeholder, however, after the process description was completed, the facilitator used the process description tool to ensure that no information was missing for the project development.

The data required to feed the computational model would be estimated by the key stakeholder, so there was no need for data collection. Workshop 1 started 15 minutes late because the key stakeholder was not available at the scheduled time. With the description provided by the key stakeholder in workshop 1, it was possible to create the conceptual model. The meeting was recorded, which facilitated further analysis.

After workshop 1, the facilitator, who also worked as a modeler, watched the recording of workshop 1 and noted down the entire description of the process. With this, she created the conceptual model. During the conceptual modeling stage, the facilitator utilized the Cawemo software. Despite IDEF-SIM (Montevechi et al. 2010) being primarily designed for simulation purposes, we decided to adopt the BPMN technique. According to Proudlove et al. (2017), BPMN offers a straightforward starting point for stakeholders participating in DES studies, particularly those with limited knowledge. Dani et al. (2019) further support this notion by asserting that BPMN is a widely used notation in the industry and is easy to comprehend.

In workshop 2, the conceptual model was validated by the stakeholder, requiring a few modifications. We present stakeholder perceptions of the conceptual model results:

Company owner (stakeholder): "*The BPMN is great. I'll take the BPMN and put it on the wall.*"

Analyzing the conceptual model, the stakeholder said that the press machine used in the sublimation process is the bottleneck of the process. Therefore, a deeper analysis was required to comprehend and enhance the process. Consequently, the brainstorming stage was initiated, discussing some potential scenarios to be experimented in the computational model. The idea analysis tool was utilized to verify the feasibility of the proposed experimentation. For instance, an idea may be disregarded if it is complex to be programmed and implemented in the actual system, necessitating an extended period.

As it was mentioned that the press was the bottleneck of the process, the stakeholder listed all types of presses available in the market that he was willing to purchase but did not know which one would lead to higher productivity and at the same time be suitable for the company's reality. Hence, four different scenarios were defined to be tested in the computer model. A list of ideas was created, containing the scenarios tested in the computer model. Therefore, the meeting ended with the scenarios the company would like to experiment with. The researcher completed the computer model and configured the scenarios after workshop 2 and presented them in workshop 3. The modeler utilized the Promodel software to build the computer model. Figure 2 illustrates the object of study during the modeling process.

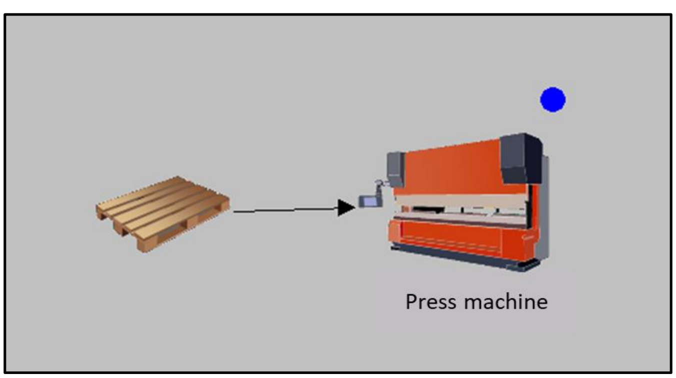

Figure 2: The object of study during the modeling process.

Workshop 3 began with the validation of the computer model. The facilitator presented the model to the stakeholder and ran it. The results were presented, and the stakeholder agreed that the computer model represented the real system, comparing, especially, the outputs of the model with the results obtained in the real context. Thus, the scenario presentation activity was started and several discussions were raised between the facilitator and the stakeholder. The stakeholder really appreciated the results, and claimed that the model reinforced something he believed, but was unsure if it would get the desired result. We present some stakeholder perceptions about the computer model results:

Company owner (stakeholder): "The model will definitely help me make a decision on which machine I should buy... I was wondering if it's worth buying a bigger or smaller machine, having two employees or just one, I made some calculations on paper... but with the help of this model, it's already decided what is best to buy. That's really great."

Through the visual analysis of the participant and their voice, it was evident that they were extremely enthusiastic about the technique and how the simulation could provide results that would justify investments in the production line. As an action plan, which had already been considered by the company owner, it was agreed that he would purchase the machine that provided the best benefit for the company in the next few months due to the cost of the material. Therefore, to avoid delays in the project's completion, since the machine purchase would occur in a few months, Workshop 3 had to be adapted. The feedback receiving activity, which was originally scheduled for Workshop 4, was added.

Regarding feedback on the intervention, the stakeholder reported that the online study was excellent, and he did not experience any issues. The fact that there were no in-person visits did not hinder the development of the models. The stakeholder considered this online approach to be better because it saved time on the project.

Thus, the stakeholder confirmed that the model accurately represents the real system, it enhanced their understanding of the process and will aid in decision-making. Additionally, we inquired if they would recommend the framework application to another company. In response, they said that they would definitely recommend it and had a great impression of the study.

Based on the feedback received, we determined that the framework and study successfully achieved their objectives. The feedback provided a greater understanding of the process, and the use of a simplified model aided decision-making. The online format of the study was also found to be efficient and yielded good results. These findings suggest that online facilitated DES can be effectively utilized in small industrial environments.

5 CONCLUSION

The current article introduces the FaMoSim framework, which is the outcome of research that addresses the limitations encountered in simulation projects in contemporary industries. With Industry 4.0 demanding swiftness and adaptability to support decision-making, facilitated simulation is a valuable resource. The FaMoSim framework consists of four phases: Kickoff Meeting; Conceptual Modeling (workshops 1 and 2); Computer Modeling (workshop 3); and Feedback (workshop 4). It takes place in an online facilitated environment, where stakeholders can express their preferences, explore various options, and actively engage in the facilitated DES project.

The proposed framework was implemented in a real case to evaluate its feasibility. With the stakeholder's active involvement, they were fully engaged in the project. Conducting an online study was deemed appropriate and produced significant outcomes for both the company and the literature. The simulation model was rapidly developed with limited data and details, yet still enabled the stakeholder to gain a better comprehension of the process and facilitate decision-making. Consequently, the objectives of FaMoSim were accomplished.

For future directions, we propose utilizing the framework on other companies of varying sizes, such as large and medium enterprises, and utilizing the framework on several cases with a varying degree of complexity in the companies, to compare the outcomes and present more comprehensive analytical discussions for the literature. We recommend analyzing (i) the use of data (estimated vs. actual data); (ii) development of action plans; and (iii) implementation and follow-up of improvements in the real system. We encourage conducting more studies focusing on different processes, including services.

Additionally, to create a quantitative measurement to reflect the success of FaMoSim in any environment can be very useful. As well as to create a set of computer tools linked to the FaMoSim methodology, like a package that may help in implementing the simulation.

The paper does not aim to make comparisons with other solutions available in the community, but rather to present the results of utilizing FaMoSim. Studies on comparisons (e.g., facilitated DES and traditional DES) can be conducted as suggestions for future work, as well.

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